Integrated AlGaAs Devices for Non-linear Applications

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Abstract: The heterogeneous integration of AlGaAs-on-insulator has great potential for nonlinear optics. This talk will explore chip-scale bonding and transfer printing techniques for the development of integrated photonic chips for second- and third-order non-linear applications. © 2019 The Author(s)

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Ever since the 1980s, silicon photonics has been at the forefront of research thanks to its CMOS compatibility, high index contrast and transparency at telecommunications wavelengths, allowing for large-scale manufacturing of highly functional photonic integrated circuits (PICs) [1,2,3]. Despite its many advantages, however, silicon lacks the Pockels effect and suffers from high nonlinear losses from two-photon absorption (TPA) at telecom wavelengths [4]. These issues, which are a consequence of the bandgap of the material and the centrosymmetric structure of the crystal, impose fundamental limitations on the use of the widely-spread silicon-on-insulator (SOI) material platform in non-linear photonics [5].

Thanks to its strong second and third-order nonlinear coefficients, Aluminium gallium arsenide (AlGaAs) is a far more appealing material for non-linear optics, reason why it has been crowned the *silicon of nonlinear photonics* [6]. Moreover, its bandgap can be easily increased to values above 1.3 eV by varying the percentage of aluminum, thus mitigating TPA at telecommunication wavelengths [7]. To date AlGaAs PICs have been predominantly fabricated on their native GaAs substrate to ensure the epitaxial growth of high quality heterostructures. The major drawback of GaAs/AlGaAs waveguides, however, lies in the challenging fabrication methods, specifically dry etching, required to fabricate such devices[8,9]. This, combined with the low modal confinement in the vertical direction, limits the ease by which the phase matching or dispersion profiles required for nonlinear processes can be engineered, often resulting in high propagation losses [10,11]. Recently, however, the integration of AlGaAs on a silica cladding layer, i.e. AlGaAs-on-insulator (AlGaAs-OI), has proven to be an efficient way to expand the capabilities of AlGaAs for nonlinear photonics [12,13].

Using this material platform, we recently demonstrated second harmonic generation for the first time in an AlGaAs-OI waveguide at telecom wavelengths (Fig.1(a))[12], achieving a maximum internal normalised efficiency of 1202±55%$W^{-1}cm^{-2}$ for a 100 fs pulsed excitation wavelength at 1560 nm. Supercontinua spanning ~0.5 octaves (-30dB level) have also been obtained (Fig.1(b)), with propagation losses as low as 1.5dB/cm at telecomm wavelengths. These results are important for new chip-scale devices for sensing, metrology and quantum optics.

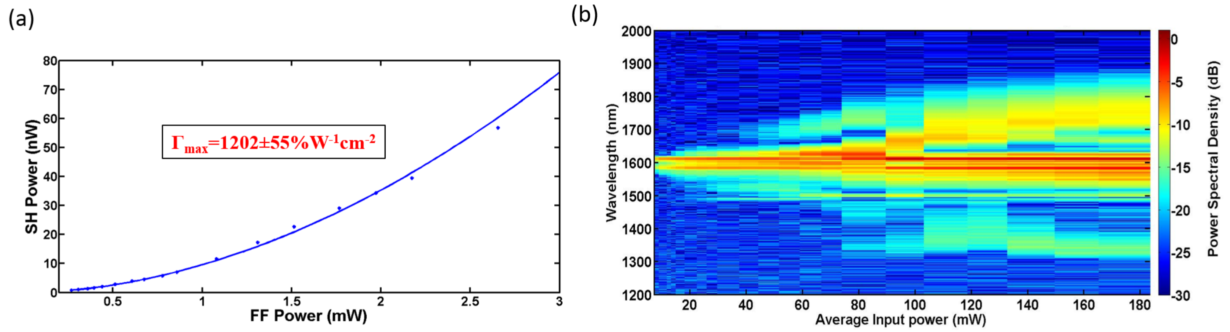

Fig.1. Nonlinearities in AlGaAs-OI waveguides: (a) Experimental result showing the quadratic behavior of the generated second harmonic (SH) for increasing power in the fundamental frequency (FF) input at 1560 nm. (b) Supercontinuum generation showing the formation of a Raman soliton and corresponding dispersive wave.

We have also explored the use of transfer printing (TP) as an alternative method to heterogeneously integrate AlGaAs devices on silicon host substrates [14]. TP is a process in which pre-processed devices are detached from their native substrate, transferred and bonded onto a receiver platform (Fig.2(a)). Using a TP technique with a very accurate alignment procedure [15], we have demonstrated the integration of an AlGaAs micro-disk on a silicon bus waveguide for four-wave mixing applications (Fig.2(b)). The efficiency of these hybrid devices are in the range of ≈-25dB from on-chip optical power as low as Pp=2.5mW, making them comparable to state-of-the-art monolithic silicon devices, with identical Q-factor, at low on-chip optical powers (~33dB at 0.7mW)[16]. In contrast to silicon, however, these devices do not exhibit TPA saturation for high on-chip optical powers. This experiment shows that TP offers a powerful tool for the development of complex heterogeneous devices that combine the desirable non-linear properties of AlGaAs with the large volume manufacturing capabilities of the SOI platform.

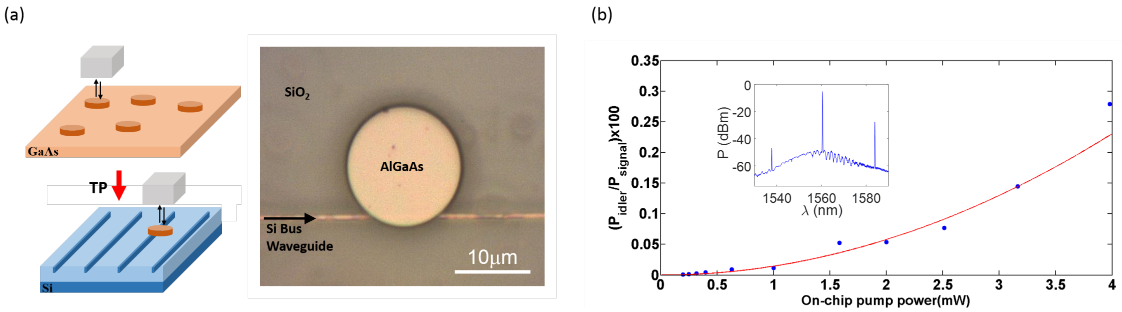

Fig. 2. Transfer printing of an AlGaAs micro-disk: (a) Schematic of the TP process of an AlGaAs micro-disk from its native GaAs substrate to an SOI receiver using a PDMS stamp; (b) Optical picture of an AlGaAs micro-disk bonded on an underlying bus silicon waveguide; (c) Experimental result of FWM efficiency as a function of on-chip power. The inset graph shows the measured FWM spectrum with the idler peak (left), pump peak (centre), and signal peak (right).

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